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about half-inch thick, which, by the three holes C, drops upon three studs screwed into the upper surface of the wheel of the vertical spindle carrying the speculum. B is a plate about the same thickness as A, placed on A's surface, and easily sliding within the ribs cast on the edges. On the upper surface of B, the speculum rests on its plates. The ends of B are curved, as in the figure, and as the plates A and B revolve, carried by the vertical spindle, the curved ends of B are *each* brought, *once* in a revolution, in contact with a pulley or roller fixed in the upright wall-plate of the machine, and adjustable as to proximity. The contact of the roller forces B to slide, smoothly and regularly, athwart A, producing the effect of a regulating or correcting cross stroke, amidst all the circular ones, and quite annihilating all ring-like tendency. The amount of lateral thrust necessary is not great, and I have used from one inch with a nine-inch speculum to one and a half or two inches with a two-foot speculum. With a shorter proportion of focus, less than this would be sufficient; for its effect is to reduce in some degree the parabolic tendency of the machine.

"The improvement of definition, as well as of certainty in the operation, which this simple arrangement produces, is most striking, and gives, I would almost venture to say, the last touch of perfection to the machine.

"*Valetta, 24th November*, 1852."

On the Figuring of Specula. By Warren De La Rue, Ph.D., F.R.S.

It has been said of the reflecting telescope, that "no one, competent to form a judgment on the subject, was ever satisfied with such an instrument, excepting the man who made it." This remark, inasmuch as it may be referred to the definition of a fixed star, is so true, that, in my own case, I include the maker of the instrument as also one of the dissatisfied parties. At the same time it must, however, be stated, that I usually succeed in producing thirteen-inch mirrors, which define the planets *Mercury*, *Venus*, *Mars*, *Jupiter*, *Saturn*, and *Uranus*, with the surface of the moon, and particularly its *bright* limb, in a manner rarely equalled, and never surpassed, by any of the refractors which I have yet had an opportunity of looking through. I am, however, free to confess, that they defined a fixed star much more satisfactorily than my best mirrors.* I am, therefore, inclined to believe that it requires a far more accurate figure in order to show a *star free from rays*, in the case of a reflector, than in that of a refractor. Difficult as the attainment of this object has hitherto proved, recent results of my own, as well as those obtained by Mr. Lassell by means of his "transverse-motion," lead me to hope that the obstacles in the way of that attainment are not insurmountable. The design of the present communication is, indeed, to bring under the notice of the Society two additions to Mr. Lassell's polishing-machine; which,

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* I have seen the components of ω *Leonis* neatly separated by the mirrors to which I allude.

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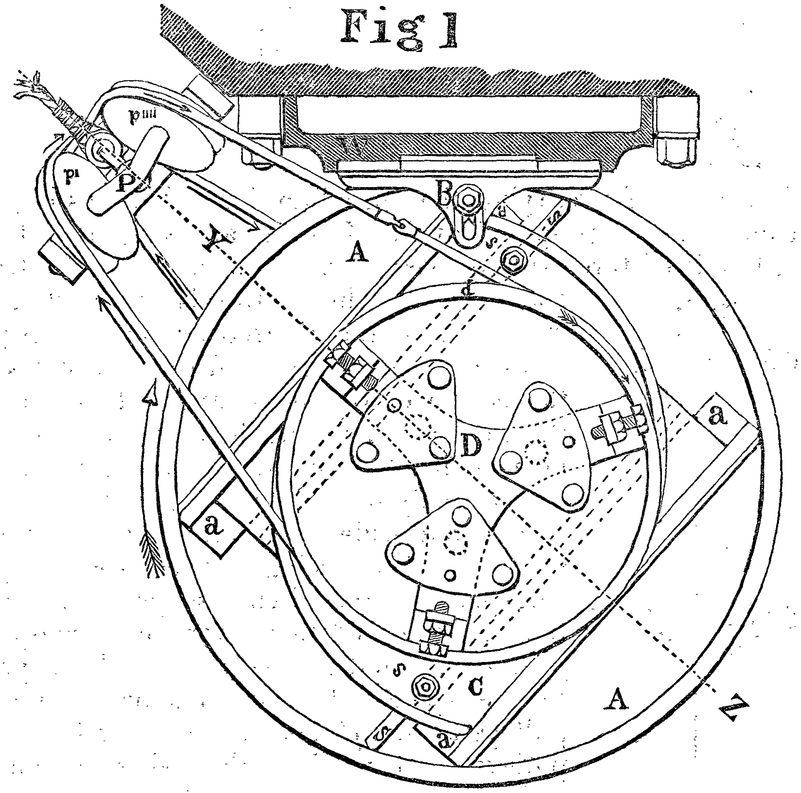
in conjunction with the "transverse-motion," have enabled me to produce figures showing as discs the components of such stars as *γ Leonis* and *α Geminorum*, whenever the state of the atmosphere admits of the use of magnifying powers from 500 to 700. With a low power (150) a bright star is surrounded by rays, so faint, however, that they appear reddish in comparison with the intense brilliancy of the nucleus.

By referring to Mr. Lassell's description of his "transverse-motion," it will be perceived that the cross-stroke occurs always in the direction of the same diameter of the speculum; a result which it appeared to me very desirable to obviate, inasmuch as the recurrence of the change of excentricity at precisely the same epoch must have some tendency, however small, to produce an irregularity of figure. In adopting the "transverse-motion," I therefore superadded a very simple contrivance for causing the speculum to rotate independently of the cam-plate. This arrangement is delineated in figures 1, 2, and 3, which are drawn to a scale of one inch to the foot, and also represent so much of the machine as is necessary to a clear comprehension of its position in relation to the other parts. Figure 1 is a plan; figure 2 a sectional elevation through the dotted line Y Z of figure 1; and figure 3 a back-view of a swinging pulley-frame.

Fig 1



I is the lower spindle of the machine, on which is keyed the worm-wheel K, to three projections from which is screwed the pan A. On the bottom of the pan are screwed two guides, *a*, be-

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tween which the cam-plate, *c*, slides, when acted upon by the roller *b*, in consequence of its own rotation in the direction of the arrow. The roller *b* turns freely on a spindle, adjustable, for the purpose of altering the throw, in the slotted plate B, which is fastened to the wall-plate W, shown in figure 1, but not in figure 2.

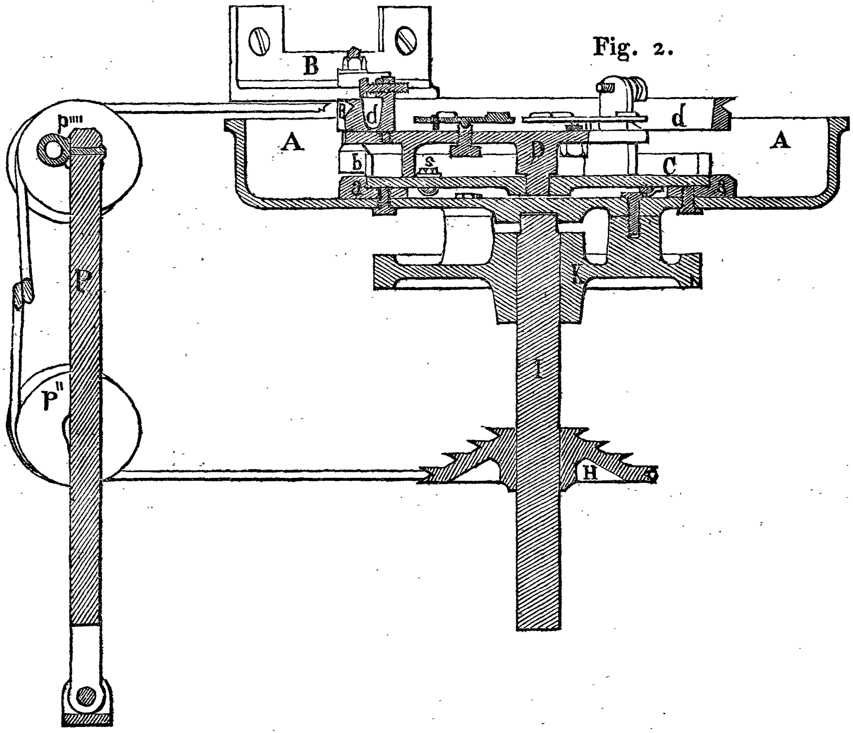
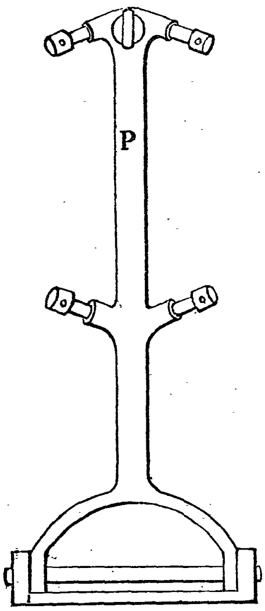


Fig. 2.

The tripods for carrying the speculum, instead of resting upon the cam-plate, as proposed by Mr. Lassell, are supported by the capped ends of three screws passing through the arms of a tripod-stand D, to which arms is attached a light wrought-iron rim *d*, grooved on its periphery so as to receive a gut. An axis projects from the centre of the arms, and enters a hole in the cam-plate: its shoulder does not, however, bear on its surface; so that the arms are supported solely by the three legs projecting from their under-side. In order to prevent the speculum from being carried round by the cam-plate, a crossed endless gut is led round the rigger *d*, and then over the guide-pulleys *p'* and *p''*, round the speed-rigger H, keyed on to the spindle I, and then over the guide-pulleys *p'''* and *p''''*, back to *d*. The four guide-pulleys are carried by the swinging-frame P; and to an eye at the back of this frame is attached one end of a rope, which passes over a pulley, and carries a tightening weight at its other end. In consequence of this arrangement,

Fig. 3.



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the speculum, instead of rotating in the same time as the cam-plate, has, on the contrary, a slower motion, though revolving in the same direction.* The cross-strokes can, therefore, recur along the same diameter of the speculum only after many revolutions, on account of the ratio of the diameters of the two riggers *d* and H; which, for the greatest diameter of the latter (that hitherto used) is as 1·69 : 1; the cam-plate rotating 169 times, while the speculum rotates 100 times.

The swinging-frame P is so placed, that its pull is perpendicular to the guides *a*, when the cam-plate has completed its stroke; the tightening-weight, therefore, cannot then move it in any direction. As the pan continues its rotation the weight would, however, pull the cam-plate towards its rim, and increase the throw beyond that given by the roller *b*, unless prevented. To avoid such an occurrence there are two stop-bars, S, adjustable beyond the cam-plate to suit the various throws which may be given to it; namely, from 0 to 2·2 inches on each side of the centre. Each stop passes through a fixed guide at one end and a screwed-staple or eye, *s*, at the other; by drawing this eye tight by means of the nut *s*, the stop is held securely in its place.

None who have used a Lassell's polishing-machine can have failed to be struck with the uncertainty and irregularity of the motion of the polisher around its axis, the quick-crank pin; and to have experienced a strong desire to have this motion as much under control as all the other movements of the machine. The polisher, being quite free to rotate, usually zigzags in one or other direction; but seldom rotates smoothly, and certainly never with any approach to a constant velocity-ratio, however attentive the operator may be in regard to the due distribution of rouge and water, for the purpose of rendering the resistance as uniform as possible. This irregular action did not escape the observation of Mr. Lassell, as he some time since proposed a plan for driving the polisher by means of a gut or band from a pulley working on an axis affixed to a horizontal swinging frame, which, moving to and fro as the polisher was carried round, maintained a constant radial distance between the polisher and its driver. Mr. James Nasmyth, in describing this arrangement to me, in a letter dated October 9th, 1850, proposed another plan. It consisted in fixing a series of long pegs around the periphery of the polisher, and placing a stationary stop in such a position that one peg after another would come in contact with it, each time the polisher was swung towards it, thus causing the polisher to move through a small arc at every throw. After having tried several schemes with indifferent success, I devised the apparatus presently to be described, which is so simple, that I am only surprised it did not occur to me from the first.

Figures 4, 5, 6, and 7, drawn to a scale of three inches to the

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* It is my intention to make a slight addition to the swinging-frame, in order to allow of an open gut being used, so as to have the facility of driving the speculum in the contrary direction also.

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foot, are different views of a new quick-crank in substitution of that employed by Mr. Lassell. Figure 4 is an elevation of it, and of as much of the other parts of the machine as is required for the comprehension of the position of the new crank in respect to them. Figure 5 is a section of the crank-pin, and a fixed wheel, which is keyed thereon. Figure 6 is a plan of the new crank removed from the pin shown at figure 5; and figure 7 a sectional elevation of it, through the dotted line Y Z of figure 6.

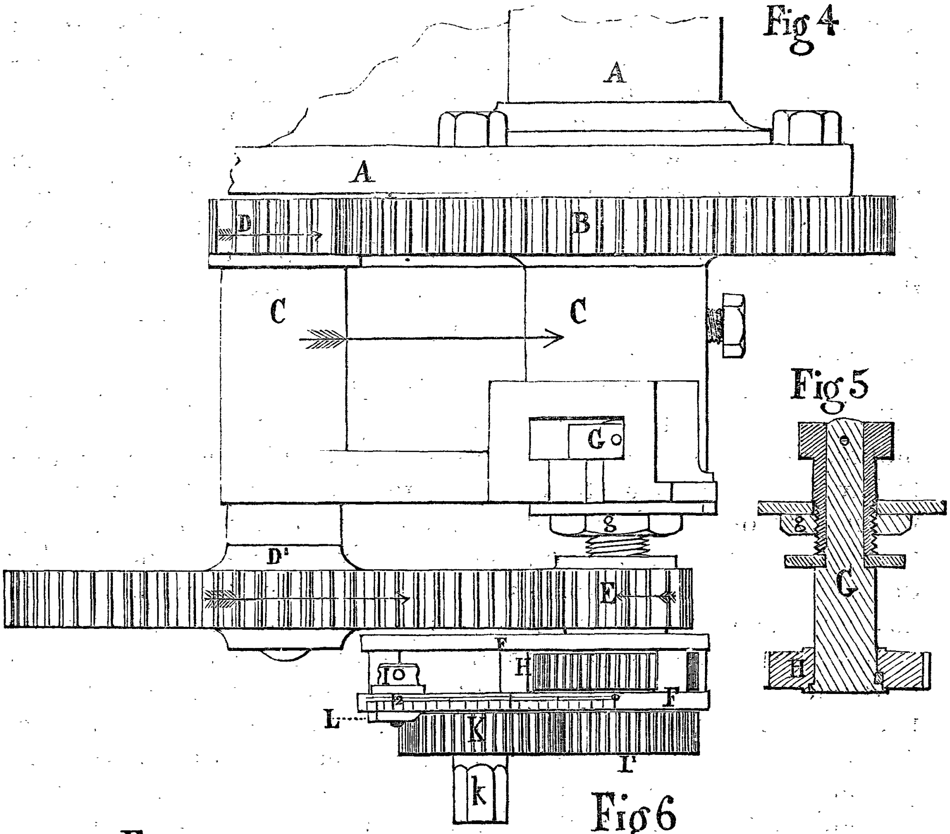
Fig 4

Fig 5

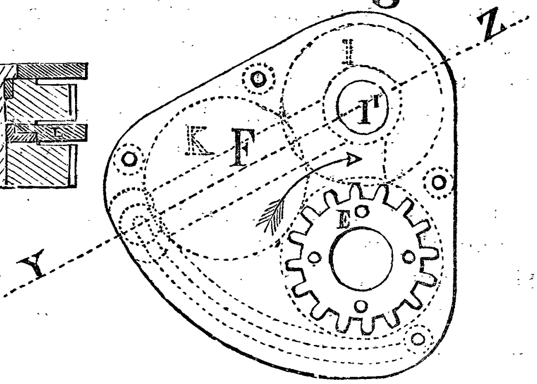
Fig 6

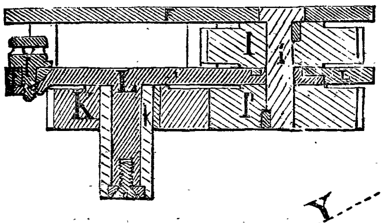
Fig 7

A is the upper fixed bracket screwed to the wall-plate, and carrying the upper spindle of the machine. On this spindle is fixed the train-bearing arm C C, which revolves in the direction of the arrow. B is a wheel of 75 teeth, screwed fast to the fixed

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bracket A, and geering with the pinion D of 16 teeth. The pinion D, and the wheel D′ of 75 teeth, are keyed on to a common spindle, which rotates in the arm C. The wheel D′ geers into the pinion of 16 teeth E, to which is fastened the triangular crank-frame F, composed of two wrought-iron plates, kept apart by four pillars, which are rivetted into them. The pinion E, and, consequently, the frame F, rotates freely on the spindle G, with a velocity ratio in respect to that of the arm C, represented by $\frac{75 \times 75}{16 \times 16} : 1$. Hence it would produce 21·97265 hypocyclic loops for one revolution of the upper spindle; on the supposition, however, that the lower spindle I, fig. 2, remains at rest: but as motion is given to this usually in a contrary direction by means of a gut working in one or other of the grooves of a pair of speed-pulleys (one on the upper and one on the lower worm-shaft), the number of loops varies with the velocity with, and the direction in, which it is driven.

The crank-pin G, which it will be remembered, from Mr. Lassell's description of his machine, may be adjusted so as to be either concentric with the upper spindle or at any degree of excentricity within the range of the machine, namely, five inches, is seen best in the sectional view, fig. 5. It is composed of the spindle proper and a hollow socket, into which this is held by a removable pin; the lower part of the socket being screwed, and carrying the nut *g*, surmounted by a washer: between the shoulder of the spindle proper and the end of the screwed socket is inserted a washer, so as to form a good bearing surface for the pinion E. On the lower end of the spindle G is keyed the wheel H, of 52 teeth. I and I′ are two wheels, each of 52 teeth, keyed on to a spindle *i*, which rotates freely in the rectangular crank-frame F; the wheel I geering in the fixed wheel H, receives a rotatory motion as the crank-frame carries it round it; I′, fixed on the same spindle as I, geers into the wheel K, having also 52 teeth: this is fastened on the hollow steel spindle *k*, which rotates freely on the spindle L, projecting from, and being a part of, the radial arm L. L is an arm moving on the spindle *i*, like a rule-joint, and adjustable by means of the circular slot at a position either concentric with the crank-pin G, or at any excentricity up to two and a half inches, the lower plate of the crank-frame being pierced with that view to an extent indicated by the dotted exterior outline of the arm L, the inner circular arc, the exterior outline of the wheel H, and the radial line joining it (see fig. 6). The screw *l* serves to hold the arm L firmly in its place. The effect of the epicyclic train H I, I′ K, the teeth of each wheel being equal in numbers, is to annihilate so much of the rotary motion of the spindle *k* as arises from its revolution around G, and hence to produce parallelism in respect to the arm C C; it, however, continues to rotate relatively to a fixed point of the machine once for every revolution of the main arm C C. The lower part of the spindle *k* is made hexagonal, in order to prevent the polisher from rotating without control; it is, however, quite at liberty to move up and down, so as to follow the

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curvature of the speculum. As the rotation of the spindle *k* is compensated in regard to the arm C C, it follows that any line of the polisher parallel with it always retains this parallelism, and, consequently, that every point on its surface describes the same number of hypocyclic loops, in round numbers 22; but while the loops described by the centre are generally nearly circular, those near the periphery are much elongated.

If the polisher were made to maintain its parallelism with a fixed line in a space, and the speculum remained at rest, then every point of the polisher's surface would describe precisely the same figure. Such parallelism might be obtained sufficiently near, for practical purposes, by making the number of I′'s teeth any multiple of 21, and those of K any multiple of 22; for instance, by giving to I′ 63 teeth, and to K 66, because one rotation in twenty-two of the crank-spindle *k* is compensated by the revolution in the opposite direction of the arm C C, which carries the whole system.

These numbers would not, however, suit in the case of the speculum revolving, which it always does, but must be calculated for each velocity of the speculum; taking also into account the direction of its motion in relation to the arm C C.

I have not at present a train to produce an *approximate* parallelism (*absolute* parallelism would not be desirable) in relation to a diameter of the speculum; but I have two, besides that of equal wheels already described, either of which produces such an amount of rotation in the polisher as I have observed it take up when left uncontrolled, namely, No. 2, in which H has 52 teeth, I 52, I′ 54, and K 50: it is, therefore, represented by the fraction $\frac{52 \times 54}{52 \times 50} = 1{\cdot}08$. When governed by this train the polisher rotates in relation to the fixed frame of the machine 2·76 times for one revolution of the arm, and in the same direction; hence, in relation to the arm, it rotates in the ratio of 1·76 : 1, and describes an epicycloid of two loops, or, more exactly, fifty-eight loops for thirty-three revolutions of the arm. Twenty-five hypocyclic loops, due to the excentricity of the spindle *k*, are distributed around this curve by the periphery of the polisher, whereas its centre distributes them around a circle, and produces a hypocycloid of twenty-two loops, precisely as is done by train No. 1; but it moves through 1·14 revolution while the periphery rotates once.

No. 3 train, in which K has 52 teeth, I 52, I′ 51, and K 53; it is, therefore, represented by the fraction $\frac{52 \times 51}{52 \times 53} = \frac{51}{53} = 0{\cdot}962264$. When governed by this train, the polisher in relation to the fixed frame, rotates in the same direction as the arm with a velocity ratio of 0·172 for one revolution of the latter. The arm therefore revolves, in relation to it, with a velocity of 828 : 172. The result of these relative speeds is the production, by a point in the periphery of the polisher, of an epicycloid of five loops, or, more exactly, thirty-four loops for seven rotations of the polisher; for in this case the excentricity of the pin G becomes the

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radius of the epicycle. Around this epicycloid of five loops the hypocyclic loops due to the excentricity of the spindle *k* are so distributed by a point in the periphery of the polisher that for one complete rotation of it 129 loops are produced, while its centre describes the hypocycloid of twenty-two loops, as in the former case; but these are repeated 5·814 times for one rotation of the periphery of the polisher. This is the only train I have yet used in polishing, and is that which has given the good results alluded to at the commencement of this paper.

The various figures described in the preceding paragraphs are very much modified by the cross-motion of the machine, and also by the rotation of the speculum; but it would occupy too much space to describe the multiplicity of changes which arise.

From the foregoing statements it will be seen, that small differences in the rotation-velocity of the polisher must have a material effect in altering the relative grinding action of points at various radial distances on its surface; and hence, to ensure the reproduction of a desired result, this velocity must be taken into account as well as any other adjustable ratio in the machine.

With the view of studying the effect of any given rotation-velocity of the polisher in relation to all or any of the movements of the machine, I fix an arm on the hexagonal pin *k*, so as to represent a radius of the polisher. On this arm slide three pen-holders, in either or all of which I can place cylindrical pens, which are charged with inks of different colours. On putting the machine or any part of it into motion, the pens trace out the curves due to all or any of the movements, and thus afford a ready means of ascertaining the distribution of grinding effect. As the result of several trials of this kind, I may state that so great a difference is produced in the various figures by comparatively small alterations in the adjustments, that I believe this mode of investigation will prove of the highest value to the telescope-maker, by enabling him to form a good conjecture beforehand of the results likely to arise from various settings of the machine.

I desire to avail myself of this opportunity to acknowledge my obligations to Mr. Lassell for his ready communication, from time to time, of his methods of manipulation. I have also to express my acknowledgments to Mr James Nasmyth, for many most valuable hints in polishing and grinding, more particularly for imparting to me his plan of producing a beautifully uniform surface to specula, previous to the final pitch-polishing, by means of a grinder made up of squares of German blue-stone (hone), cemented with a composition of pitch and rosin on to a light frame of cast-iron. I attribute much of any success which I may have had to the adoption of this plan, or a slight modification of it. My alteration consists in substituting a slab of common slate for the bed of hones; the former having the advantage of always retaining its figure, which the hone-tool does not when laid on one side for any length of time. On a future occasion I may have something further to communicate respecting the employment of the slate-tool.